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A HIERARCHICAL ARCHITECTURE FOR COMPUTER MAIL SYSTEMS,(U)
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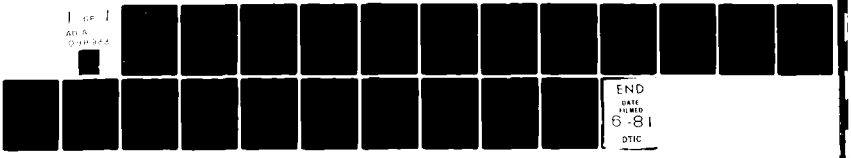

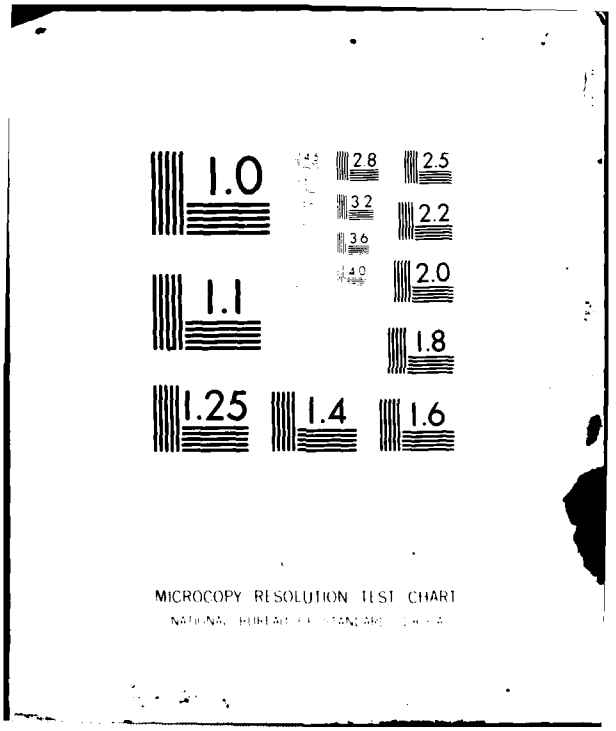
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# A HIERARCHICAL ARCHITECTURE FOR COMPUTER MAIL SYSTEMS*



by

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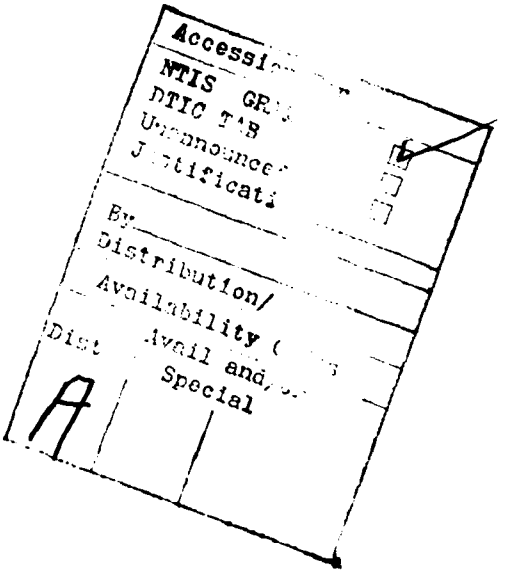

# A HIERARCHICAL ARCHITECTURE FOR COMPUTER MAIL SYSTEMS*

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## ABSTRACT

In this paper we present an architectural model for large, distributed computer mail systems. This model specifies:

1) a minimum set of functional components that supports all computer mail functions;

2) the functions and structure of each component;

3. the communication protocol needed for interprocess communication; and

4. the organization of the identification database used to support identification services in the architecture.

The computer mail protocol of the architecture is specified following the framework of the Reference Model for Open System Architectures proposed by the ISO, and each layer of the protocol is discussed in detail. The organization of the identification database is based on the same layering concept, and special emphasis is given to the role of identification services in large systems and the interconnection of various systems.

* The efforts of one of the arthors (Franklin F. Kuo) was supported by the Office of Naval Research under contract N00014-78-C-0498.

## INTRODUCTION

In this paper we present a comprehensive architectural model for large computer mail systems. Section I identifies the functions of a computer mail system, formulates a modular structure of the system suitable for all implementations and specifies the logical structure of each module (functional components) in terms of its interaction with other modules. Section II describes the general operation of the architecture by presenting the procedures needed to deliver intra- and internetwork messages and to identify system addresses in one or more mailing networks. Section III specifies the computer mail protocol (CMP) used to implement the procedures described in Section II. Section IV describes the organization of the directory system used to maintain the information necessary for the identification of system addresses. Section V summarizes highlights of the model and points out the areas in need for further research.

## I. SYSTEM FUNCTIONS AND COMPONENTS

### A. System Functions

A computer mail system is formed basically of:

1. Message files where users' messages are stored as records.
2. Message handling software comprising message processing programs and message delivery programs.
3. An identification database where the system mailbox addresses (names of users' message files) are maintained.

A computer mail system provides delivery of messages between users' message files at electronic speeds and interactive computer tools to process information before and after delivery. Message delivery in computer mail systems is carried out by identifying the recipient's system mailbox address and transferring a copy of the message from the sender's to the recipient's message file without the need for the recipient to be logged in. The composition and retrieval of electronic messages are carried out by message system users independently from the delivery of messages. We partition all computer mail functions into three independent groups: message processing functions, intranetwork addressing and delivery functions, and internetwork addressing and delivery functions.

B. Functional Components

MAILBOX (MBX) is the process dedicated to the message processing functions of the system and the maintenance of user information. The mailbox is also the interface between the message user and delivery services. Figure 1 shows the architectural framework of the mailbox. Interactions between a message system user and the system are carried out through the user interface, the set of programs that implements the commands available to the user to manipulate information before and after delivery. Messages in transit, whether being sent or received are stored in the message workspace (Fig. 1). Message delivery services are intended to be transparent to the user interface and the message system user should only be concerned with the processing of the contents of the messages. The mailbox communicates with the local mailer (MLR) by the mailer interface, which makes all necessary transformations in syntax so as to present outgoing messages to the mailer in a standard form, and present messages to the user in any locally defined form. The mailbox database (Fig. 1) provides permanent storage for messages and (optionally) a personal directory with system mailbox addresses of other frequently addressed message system users. The contents of the mailbox database can be updated only by the message system user via the user interface (Fig. 1).

MAILER (MLR) is the process dedicated to the intranetwork addressing and delivery functions of the system. A mailing network (MNT) is the union of logically connected mailers. The topology of a mailing network is totally independent of the topology(ies) of the underlying communication subnetwork(s), and each mailer belongs to only one mailing network. Figure 2 shows the architecture of a mailer. The mailbox interface of a mailer collects messages from the mailer's local mailboxes and distributes messages to those mailboxes. The network protocol handler consists of the software needed for: the billing and accounting of message deliveries, the structuring of the information of those messages, and the handling of dialogue with other mailers and the gateway mailer to identify system mailbox addresses and route the message to the proper mailboxes. Messages in transit, to and from the local mailboxes, are stored in the message buffer, which serves as a working buffer for the network protocol handler. Thus, intranetwork addressing and delivery services are transparent to the mailbox interface, and the mailboxes need only to know about the existence of their local mailers. The mailer directory database provides

permanent storage for the network's addressing information and time-stamped records of message deliveries.

GATEWAY MAILER (GMR) is the process in charge of the internetwork addressing and delivery functions of the system. A computer mail system (CMS) is the union of various mailing networks, each served by a gateway mailer. The structure of a gateway mailer is basically the same than that of a mailer. The network interface of a gateway mailer manages the interactions between the gateway mailer and mailers in the mailing network. The internetwork protocol handler handles the interactions of the gateway mailer with other gateway mailers of the computer mail system. Messages in transit, to and from users in the local mailing network, are temporarily stored in the message buffer. Thus, internetwork delivery services are transparent to the network interface and a mailer needs to know only about the existence of other mailers and its local gateway mailer. The gateway directory database provides permanent storage for internetwork addressing information and time-stamped records of internetwork deliveries. Message delivery at the internetwork level is complicated by political, technical, and social problems [5], [14], [26], [27]. However, provided that either a common transport service is aviable (e.g. X.25) or transport-level gateways support the necessary transformations between local transport services (communicating through an internetwork transport protocol), the establishment of internetwork computer mail standards is technically feasible.

## II. SYSTEM OPERATION

### A. Addressing

In our architecture delivery and addressing services are transparent to the message system users. Thus, the sender of a message needs only to enter a user-oriented description of the recipient together with the message he wants to be delivered, and not be concerned with the recipient's system mailbox address or how messages are routed to their destinations. The computer mail system must be able to assist the sender in identifying the recipient's system mailbox address from the user-level description of the recipient entered by the sender.

A message system user might well be able to describe (name) the recipient of a message in terms of the recipient's name and/or title in an organization, his organization, his geographical location and (perhaps) his computer mail system or network. We define a user-level naming format called the NOLS address [7], [8], which consists of four fields that describe the attributes of the recipients as indicated in Table 1. At the time the sender enters a message he also enters a NOLS address with what he knows about the recipient's name and/or title, organization, geographical location, and message system. When the sender instructs his mailbox to deliver the message, the mailbox transfers the message and the NOLS address to the local mailer, which is then responsible for the delivery of the message. Figure 3 shows in a simplified form the steps followed to deliver a message. A NOLS address serves as an identification query to the system for obtaining the correct system mailbox address. As is shown in Fig. 3, the procedure followed to resolve such a query consists of the forwarding of the NOLS address among mailers and gateway mailers according to the identification information maintained in their directory databases. When a mailer (gateway mailer) receives a NOLS address, the mailer (gateway mailer) examines the fields of the NOLS address and based on its directory database it determines whether to forward the NOLS address, reply with a negative acknowledgement, or send back the requested information. The identification information in the directory databases consists of non-private information that specifies who message system users are, where they are and (perhaps) what they do [6].

Once a remote mailer replies with the recipient's system mailbox address, the NEXUS (a virtual connection) between the sender's and recipient's mailboxes is created. Then, as is shown in Fig. 3, the NEXUS serves as a virtual information channel from the sender's mailbox to the recipient's mailbox for the delivery of the message. Since the message system users are allowed to ask for the delivery of messages regardless of how little information they provide in the NOLS addresses, these addresses may in some cases be ambiguous, or lack key information. In such cases various gateway mailers and/or mailers may have to be queried before the system mailbox address is obtained. If the NOLS address is very poorly specified, the system may be unable to identify the recipient's system mailbox address at all, or in some cases, respond with a list of "similar names" at given locations.

B. Message Delivery

In our model, message delivery consists of two phases: the NEXUS establishment phase and the message delivery phase. In the NEXUS establishment phase, the recipient's system mailbox address is obtained as was discussed in Part A. The message delivery phase consists of the routing of the sender's message from mailer to mailer and/or gateway mailer until it reaches its final destination. Thus, a NEXUS is a high level virtual connection between sender's and recipient's mailboxes that relies on lower-level virtual connections between the forwarding mailers and gateway mailers.

An "electronic envelope" is added to the sender's message (as well as to identification queries and updatings) being transferred to avoid closed loops in the routing of the message and the violation of users' privacy. The message itself is presented according to standard formats and data types to permit the recipient's mailbox to process the information contained in the message. This encoding of the message could also provide protection (by means of encryption techniques) against disclosure to unauthorized persons, fraudulent modification of the message, and persons disguised as authorized message system users.

## III. COMPUTER MAIL PROTOCOL (CMP)

A. Protocol Layering

The computer mail protocol (CMP) supports interprocess communication in the proposed architecture and permits a message system user to have access to any non-private computer mail resource in the system(s). For the purpose of standardization, the CMP is partitioned into layers, each concerned with a specific aspect of interprocess communication. We follow the general framework of the Reference Model for Open System Architecture proposed by the ISO [10] to partition the CMP. In the ISO model, the three layers of interest for Computer Mail are the Session, Presentation and Application layers [12]. These three layers support the establishment of logical connections between end-to-end processes (session layer), the structuring of the information exchanged between end-to-end processes (presentation layer), and the manipulation of such information according to end-user purposes (application layer). The transport layer of the ISO model [2], [4], provides end-to-end interprocess

communication between processes in different host computers, and its services will be assumed in this discussion. Applying the ISO model to the modular structure introduced in Sec. I, we see that the CMP can be organized into four layers, as is shown in Fig. 4.

B. Message Processing Layer

The functions at this layer extend those functions aimed at the automation of information flow between message system users. This layer of the CMP permits the open interworking between message system users. The set of commands defined at this layer to process information before and after deliveries is called the user interface. Various message processing applications have been implemented [15], [21], [24] and others have been proposed [20], but all of them are aimed at the exchange of textual information between individuals. The design of a user interface largely depends on the facilities available at the users' workstations and the purposes of the exchange of information. However, a generic set of message processing functions can be identified at the message processing layer. Such functions comprise [15], [22], [24]:

1. User session extablishment and termination;
2. Information retrieval (message and addresses);
3. Message editing and composition;
4. Message delivery, forwarding and reply;
5. Filing and archiving of information;
6. User help, documentation and training;
7. Customization of user interface;
8. Billing and statistics; and
9. User-level security.

C. Management Layer

The management layer of the CMP manages the delivery of user messages, and the distribution and maintenance of identification information. Table 2 gives the seven commands defined in the CMP. Each command is formed by a control and a data component. The data component contains the information to be processed by mailboxes (in message deliveries) or mailers and gateway mailers (in identification queries and updates). The control component serves as the "electronic envelope" for the data component. Such an envelope contains the information required to specify the command to be executed, and support the forwarding of

the command, closed user groups (and privacy in general) and the establishment of "time stamps" of every transaction. Time stamps of transactions permit the system to trace the message when problems arise. In addition, they represent an accurate source of information for billing and accounting purposes.

The establishment of a NEXUS between sender's and recipient's mailboxes is carried out at this layer in the form discribed in Sec. II. As is shown in Table 2, NOLS addresses are distributed by IDENTIFY commands, and DELIVER commands are used to dispatch user messages. A NEXUS is an end-to-end virtual connection at the management layer that relies upon sessions established at the session layer. Various NEXUS's may have to be established for the delivery of multidestination messages, and various sessions may have to be established to support a NEXUS if the message has to be routed through various mailers and gateway mailers.

D. Presentation Layer

The presentation layer of the CMP is necessary to allow the open interworking between heterogeneous office workstations (e.g., teletypes, graphic terminals, word processors, facsimile terminals, multimedia integrated terminals) and to permit the exchange of information in standard formats between mailers, gateway mailers and mailboxes. For these purposes this layer defines a set of structuring rules to specify formats that integrate alphanumeric text, digitized voice, graphics, and video pictures in the messages exchanged in the system. This layer relies on the concept of virtual workstation, an extension of the virtual terminal concept [1], [4]. The virtual workstation consists of a hypothetical office workstation with standard functional characteristics known by the management and message processing-level processes. Each office workstation is assigned a workstation class and profiles based on the functional characteristics of its input/output devices and the forms available to represent information. The mailbox maps the virtual workstation characteristics defined in the CMP into the physical characteristics of the local workstation.

The presentation layer is carried out in three main phases: the negotiation phase, the data transfer phase and the termination phase. These phases rely on the existence of a session between the communicating parties. The negotiation of parameters in the CMP is asymmetric, with the sender's process

always being the master of the negotiation. Parameters are negotiated when IDENTIFY commands are dispatched. Once the DELIVER command is transmitted no further negotiation is possible. The recipient's mailbox stores the message as received and upon retrieval it deletes those portions of the command it cannot output.

The information exchanged at the management and message processing layers is structured by means of a set of data types [7], [18], [23]. Each data type encodes a portion of the command being transmitted, and identifies the type of information encoded (e.g., text, digitized voice, facsimile), its location in the message and the attributes of the information. Also, we propose to provide encryption functions at this layer to provide security and privacy.

### E. Session Layer

In order to carry out the functions of the CMP, the mailboxes, mailers and gateway mailers must establish a dialogue with each other. The purpose of the session layer is to support the dialogue between presentation-level entities. This support consists of the establishment of logical connections between communicating processes and the control of the data exchanged via such connections. Because of the asymmetric, non-interactive form of communication supported in computer mail systems, a datagram-oriented approach can be used in the session layer to establish sessions between processes. With this approach, sessions are opened and closed with the same control commands used to transfer the information through the virtual connection. That is, a typical command in the session layer has the format: OPEN CONNECTION + presentation-level information + CLOSE CONNECTION. Thus, NEXUS's are supported by sessions, and sessions are handled in a datagram fashion. The control of data exchange consists of the negotiation of the parameters used at the presentation layer.

## IV. DIRECTORY SYSTEM

### A. Definition

The directory system of a computer mail system is the distributed identification database formed by the personal directories in users' mailboxes and the directory databases of mailers and gateway mailers. The functions of the directory system are to provide the message system users with an integrated

view of the identification information distributed in the mailing network(s), and to support the mapping of NOLS addresses into system mailbox addreses.

B. Organization

We propose a hierarchical organization of the directory system in which all detailed information about message system users is independently maintained at each mailer. Mailers and gateway mailers maintain common addressing information and share a standard identification procedure in order for mailers to obtain remote addressing information. Table 3 shows the four level hierarchical organization we propose. This organization permits each organization (accessing a mailer) in the computer mail system to maintain the information concerning its own members according to its own needs, and permits the message system users to have a simple, integrated view of the information distributed in the system.

C. Structure and Distribution of Information

The logical structure of the information maintained in the directory system is called the schema of the directory system. It defines the entities, relationships among entities, and their attributes. The schema of the directory system is also organized into four layers. Table 4 gives the information maintained at each level of the directory system and its structure. At the user level information is distributed according to the users' requests. At the local level, each mailer maintains all the information about its local users. This information is used to identify the recipients' system mailbox addresses. At the network level, one or more mailers in a mailing network maintains the network directory system. The information in this directory system is used to forward the identification queries to the destination mailers. At the system level gateway, mailers in the system maintain the internetwork directory system. This information is used to forward the identification queries to the proper gateway mailers.

D. Control

As it was stated in Sec. II, the identification of mailbox addresses is a store and forward procedure in which a mailer (gateway mailer) forwards a NOLS address to those processes determined from the network (system) directory. A mailer that receives a NOLS address decides from its local directory whether to send a positive or negative reply, or forward the query.

Network and system-level updating is done by means of the UPDATE command, which is dispatched when forwarding processes detect erroneously delivered commands. Local and personal directories are independently updated by mailers and users respectively.

## V. CONCLUSIONS

In this paper we have presented a comprehensive model for computer mail systems focusing on large, distributed systems and system interconnection. The most important features of this model are its hierarchical structure (that permits each component to know only a small portion of the whole system) and the fact that provision of transparent identification services (often overlooked in computer mail system design) forms an integral part of the model. The functions of the computer mail protocol were described following the Reference Model for Open System Architecture proposed by the ISO. Finally, the directory system that maintains the information needed to identify mailbox addresses was described. Its organization constitutes a trade-off between complete distribution and complete centralization of identification information given the various design constraints that arise when many organizations, various countries and several individuals are involved.

Various studies exist related to the design of computer mail systems [3], [9], [13], [16], [22] - [24], and a concensus on the use of specific protocols may be reached in the future, at least for the session and presentation layers [18], [23]. However, the specification of message processing functions remains as an open problem. On the other hand, there have been very few attempts to study the role of on-line identification databases in computer mail systems [6] - [8]. But the provision of adequate identification services will become a major design problem to permit the open interworking of message system users in the future.

Finally, we must point out that although we have only focused on techniques for the automation of information flow in office environments, the storage of multimedia information in office automation systems represents one of the most important problems to be solved in large systems and should receive considerable attention in the future.

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Table 1 - NAMING AND ADDRESSING FORMATS

| FORMAT TYPE | COMPONENTS |
|---|---|
| NOLS address | <N-field> <O-field> <L-field> <S-field><br>N-field -- Contains information about the recipient(s) of the message such as his Name and/or title.<br>O-field -- Contains information about the Organization(s), group(s) or system server(s).<br>L-field -- Contains information about the geographical Location of the organization(s) or group(s) referred in the O-field.<br>S-field -- Contains information about the System which offers the computer mail services to the recipient(s). |
| Proposed 3-layer system mailbox address | [<internetwork layer> <intranetwork layer> <local layer>]<br>Internetwork layer--Contains the name of the network specified according to the system-wide formats.<br>Intranetwork layer--Contains the name of the mailer in the mailing network specified in the internetwork layer. The mailer's name is specified according to formats particular to the network.<br>Local layer--Contains the name of the mailbox in the mailer specified in the intranetwork layer. The name of the mailbox is specified according to formats particular to the mailer. |
| NEXUS address | ( [sender's system mailbox address] , [recipient's system mailbox address] ) |

Table 2 - BASIC SET OF COMMANDS FOR INTERPROCESS COMMUNICATION

| | |
|---|---|
| DELIVER -- | Contains the user message, together with the NOLS and NEXUS address of both sender and recipient |
| IDENTIFY - | Contains the user query, i.e., a NOLS address created by the sender. It also identifies the sender for management purposes. |
| ACK-ID --- | Contains the positive reply to an IDENTIFY command with the system mailbox address and NOLS address of recipient. |
| NACK-ID -- | Contains negative reply, possibly including a "list of similar names". |
| ACK-DEL -- | Contains positive acknowledgement to a successful delivery. |
| NACK-DEL - | Contains negative acknowledgement to a DELIVER command and is possibly due to component failure, unauthorized sender, or non-existent mailbox address. |
| UPDATE --- | Calls for an update in the directory database and contains time-stamped information. |

Table 3 - DIRECTORY SYSTEM ORGANIZATION

| LEVEL FUNCTIONS | FORMED BY | MANAGEMENT |
|---|---|---|
| USER -Storage information about frequently addressed recipients | Union of personal directories at users' mailboxes | Carried out by user interacting with his mailbox |
| LOCAL -Physical storage of detailed information<br>-Control of physical access<br>-Management and description of logical and physical structure of local information<br>-Local to network data model mapping | Union of local directory systems maintained at each mailer | Carried out by mailer in a form totally independent from the rest of the system |
| NETWORK -Forwarding of control commands<br>-Error recovery<br>-Data integrity<br>-Distributed query processing<br>-Data Model mapping<br>-Query structure | Network directory system which can be either centralized in a single mailer or distributed in a mailing network | Carried out by mailers and the gateway mailer of the mailing network |
| SYSTEM --Forwarding of control commands<br>-Error recovery<br>-Data integrity<br>-Distributed query processing<br>-Data Model mapping<br>-Query structure | Internetwork directory system which can be either centralized in a single gateway mailer or distributed in the computer mail system | Carried out by gateway mailers of the system in cooperation with each other |

Table 4 - INFORMATION MAINTAINED IN THE DIRECTORY SYSTEM

| LAYER | INFORMATION | LOGICAL STRUCTURE |
|---|---|---|
| User | Information about frequently addressed recipients, primarily consisting of mailbox addresses | Each user has a user's subschema to describe the information stored in his personal directory |
| | | A network-wide user-schema is defined for all the users in a mailing network to name the recipients in terms of a standard set of entities, relationships and attributes known to the system (i.e., enter NOLS addresses). |
| Local about | Detailed information about recipients served by each mailer | Each mailer has a local schema to organize the information stored in its local directory which is independent to the rest of the system. |
| Network | Mailer addresses of organizations served in the mailing network | A network schema is defined for all mailers in the mailing network. Allows for the identification of organizations in the network |
| System | System addresses of organizations served by various mailing networks and other entity of system-wide importance | A system schema is defined for all the gateway mailers in the system. Allows for the identification of mailing networks |

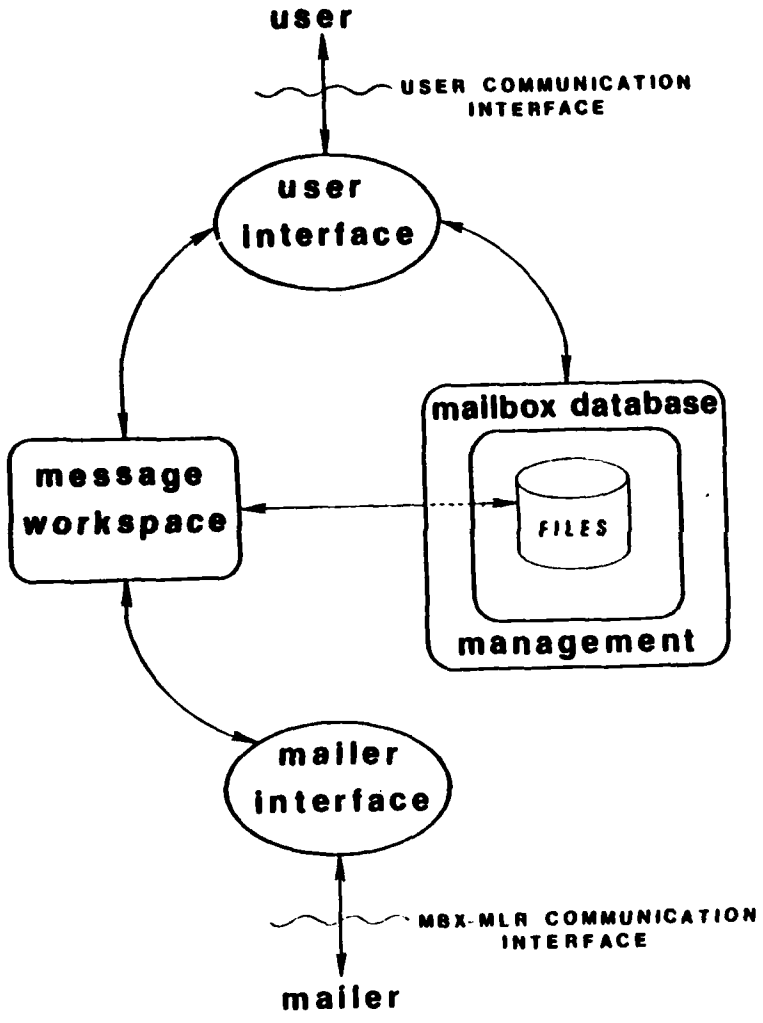


Figure 1 - MAILBOX STRUCTURE

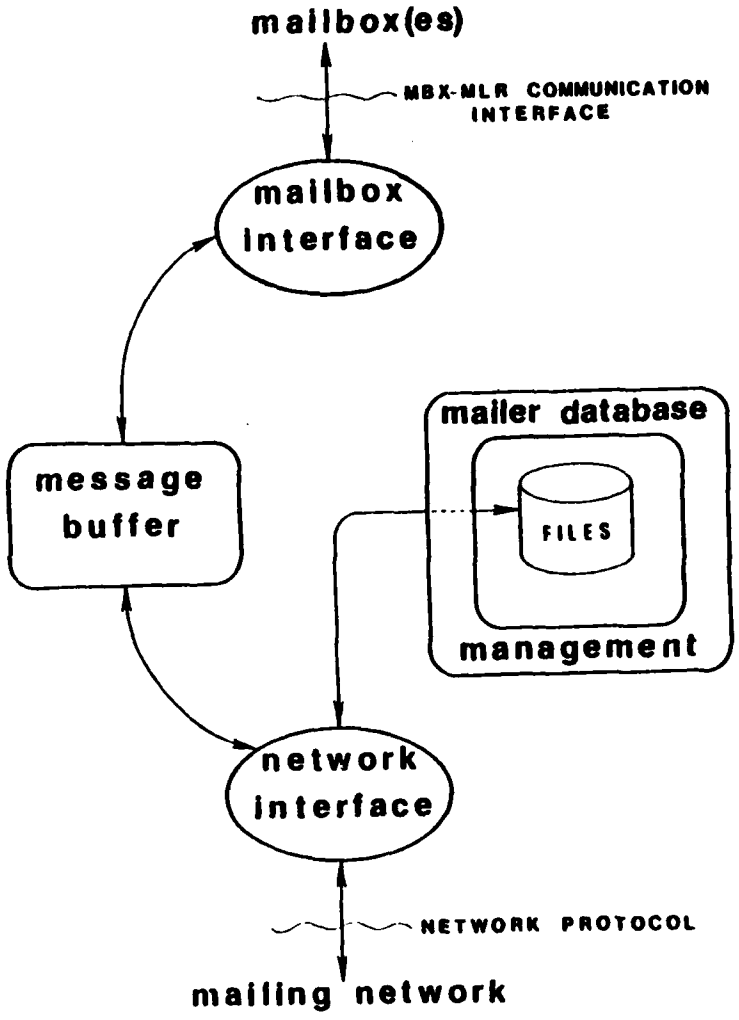


Figure 2 - MAILER STRUCTURE

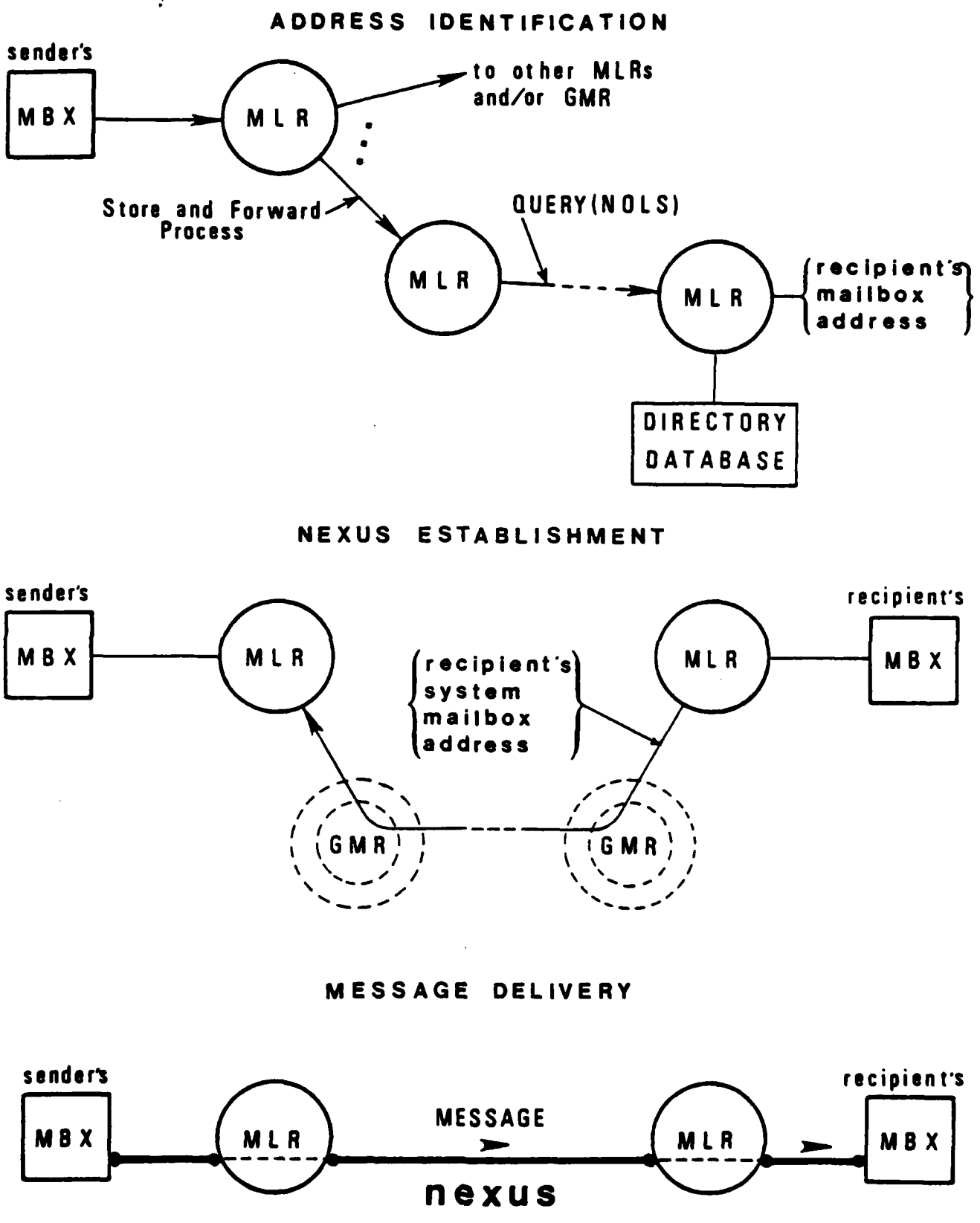


Figure 3 - SYSTEM OPERATION

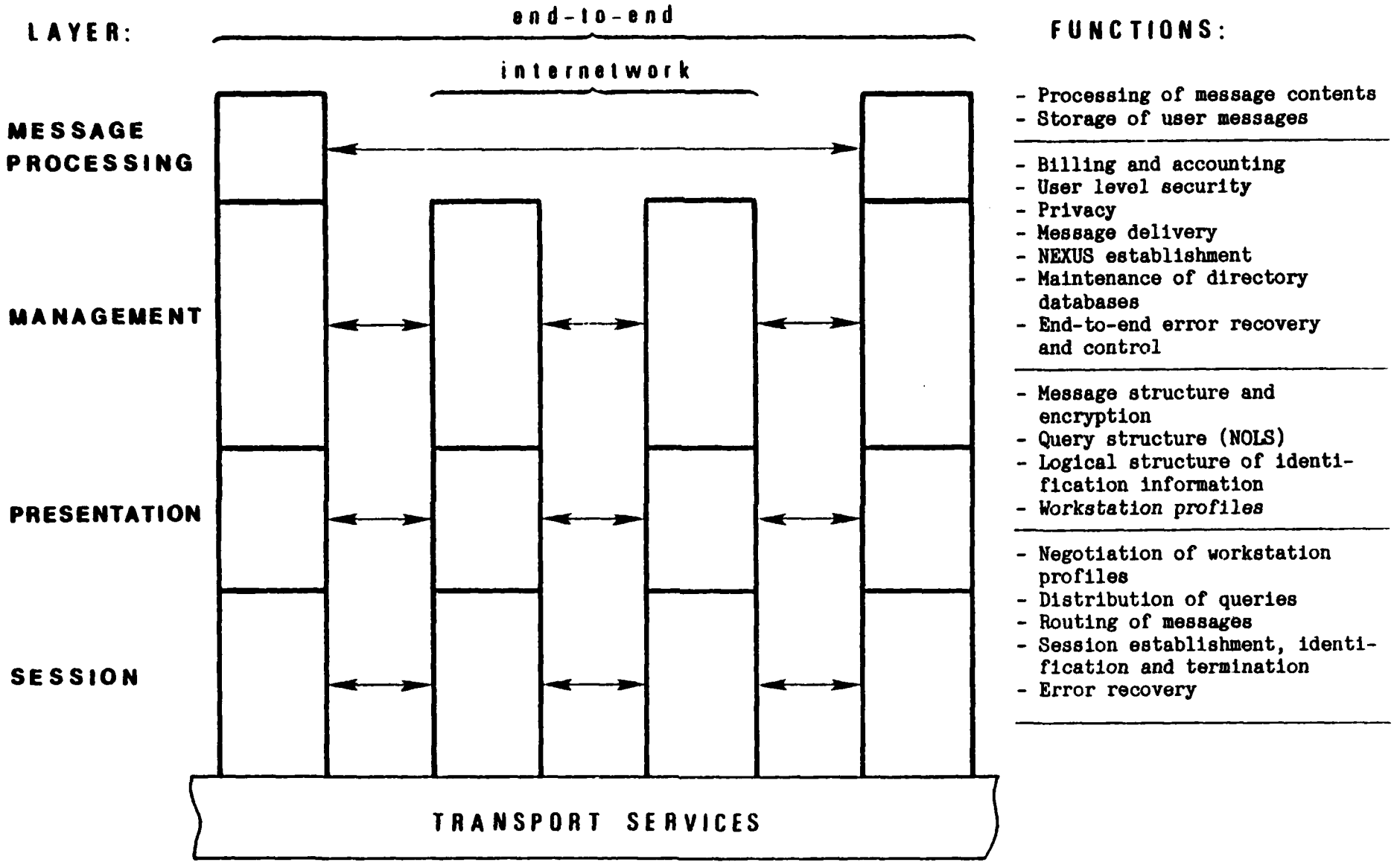


Figure 4 - COMPUTER MAIL PROTOCOL


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